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NRL Report 5078
Copy No. 36

TRANSMISSION OF LIGHT IN COASTAL WATER

[redacted]

W. S. Plymale, Jr. and G. L. Stamm

Photometry Branch
Optics Division

February 4, 1958

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NAVAL RESEARCH LABORATORY
Washington, D.C.

[redacted]

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From: Commanding Officer, Naval Research Laboratory
To: U. S. Department of Justice, Assistant Attorney General
Civil Division, Commercial Litigation Branch

Subj: CHARLES E. PFUND V. UNITED STATES, COURT OF FEDERAL CLAIMS NOS. 276-87C AND 592-88C

Ref: (a) DOJ ltr 154-276-87/154-592-88 of 5 Jun 95

Encl: (1) NRL Memorandum Reports cover pages

1. Per reference (a), we have reviewed all the reports in the 5 June 1995 letter from Mr. Hunger and Mr. DiPietro.

2. The material contained in enclosure (1) describes measurements made relating to optical communication with submarines. The instruments and hardware used in the measurements is quite out of date and not in use currently. For example, the electronic circuits described employ vacuum tubes rather than solid state devices.

3. The measurements results do not reveal any operational details, but rather are descriptive of the instrument capabilities, the optical properties of water, and some atmospheric phenomenology.

4. None of the information contained in these reports requires any further protection.

5. In our opinion, every report itemized in reference (a) can be downgraded to UNCLASSIFIED and assigned a distribution statement A: Approved for public release; distribution unlimited.

CHARLES ROGERS
By direction

[redacted]

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[redacted]

AN EXPERIMENT ON TRANSMISSION OF LIGHT SIGNALS FROM A SUBMARINE TO AN AIRCRAFT IN COASTAL WATER

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NAVAL RESEARCH LABORATORY
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ABSTRACT

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The prospect of signaling between submerged submarines and airplanes in flight is a very interesting and potentially useful one to the Navy. Pulsed-light signaling from a submarine to an aircraft was achieved with limited success in previous experiments. The most successful runs were made off the east coast of Florida where horizontal air ranges up to 8600 feet for keel depths at 127 feet were obtained with the airplane at a height of 2000 feet.

In recent months the transmitter has been completely redesigned optically to give greater horizontal ranges for low-flying aircraft. In addition the firing circuit has been improved to give 0.4-microsecond pulses and peak dissipative energies near 20 megawatts at flash rates up to five flashes per second.

Reported here is a daylight-to-night series of runs made in the Block Island area off Rhode Island on September 18, 1957. The USS TUSK transmitted signals to a P2V-5 flown from the Naval Air Station, Brunswick, Maine. In spite of the high optical density of these coastal waters, the data were fairly good. A typical night run was made at a keel depth of 90 feet for the submarine and an aircraft altitude of 1000 feet. The horizontal range was 1.9 statute miles. For daylight runs the ranges were near zero. These and other data have been tabulated to summarize the work thus far on this problem.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem N95-01
Project NS 674-100
BuShips Problem S-1828

Manuscript submitted December 10, 1957

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TRANSMISSION OF LIGHT IN COASTAL WATER
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AN EXPERIMENT ON TRANSMISSION OF LIGHT SIGNALS FROM A SUBMARINE TO AN AIRCRAFT IN COASTAL WATER
[redacted]

INTRODUCTION

The prospect of signaling between submerged submarines and airplanes in flight is a very interesting and potentially useful one to the Navy.* In a previous report† it was proved conclusively that this was feasible by transmitting a very-high-intensity short-duration light pulse from a submarine through the sea and the atmosphere to an airplane. In this report also may be found the limited data collected when light-pulse transmissions were carried out at sea between the USS SARDA and a P2V-7 airplane. Daylight and nighttime runs are recorded along with a brief description of the apparatus. Positive results were obtained in the Jacksonville area under the following conditions: nighttime, clear ocean water, rough sea surface, hazy atmosphere, and no ambient moonlight. The greatest detectable horizontal range was approximately 1.5 miles when the airplane was flying at an altitude of 2000 feet and the submarine was submerged to a keel depth of 127 feet.

However, the amount of data collected at the time was limited, and it was thought that the ranges could be extended by modifications in the equipment. Therefore, plans were made for a new field experiment, the objectives of which would be twofold:

1. to modify the transmitter and the receiver so that greater detectable ranges could be attained in situations where the airplane would fly at altitudes of 500 to 1000 feet and the submarine would submerge to various depths, and

2. to accumulate more data to show the usefulness and limitations of the present equipment under various field conditions.

These additional data, obtained with a modified transmitter and receiver, are reported herein. The cone of radiant energy from the transmitter has been made wider, and also the pickup unit of the receiver is sensitive over greater angles. With this new equipment, runs were made in the Block Island area off Rhode Island resulting in a typical horizontal range of 1.9 miles attained during the night with the submarine at a keel depth of 90 feet and the airplane at an altitude of 1000 feet.

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*A previous study in this series which might be of interest to the reader is: G. L. Stamm, W. S. Plymale, Jr., and C. M. Whitfield, Jr., "The transmission of Pulsed-Light Signals from Land to Aircraft," NRL Report 4820 ([redacted]), September 1956

†G. L. Stamm and W. S. Plymale, Jr., "Some Preliminary Measurements on the Transmission of Light Signals from a Submarine to an Aircraft," NRL Report 4936 ([redacted]), June 1957

[redacted]

Submarine and airplane personnel have shown enthusiastic interest in this type of equipment wherever field tests have been arranged, but there are a considerable number of studies to be undertaken in considering all aspects of the problem. Since many of these studies must be performed using submarines and airplanes, the difficulties involved in obtaining data are often numerous and complicated.

MODIFICATION IN THE TRANSMITTER

To produce a broader energy pattern it was necessary to increase the discharge energy per pulse and to redesign the optics around the Mullard LSD2 flashtube. A parabolic mirror with a diameter of 9 inches and a focal length of 1-3/8 inches was installed with a 9-inch window in a new transmitter housing. The flashtube with a 4-cm gap was mounted coaxially in the mirror and adjusted near the focal point to give the broadest beam possible with such an extended source. Figure 1 is a cross-sectional drawing with a few selected rays drawn to show how light from two points in the discharge column is reflected outward and through the window.

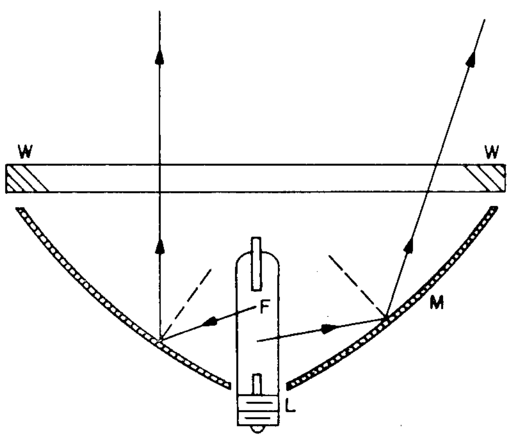

Fig. 1 - A four-cm-gap lamp L placed coaxially in a nine-inch parabolic reflector M. Practically all of the light is transmitted through the window W. The letter F is the focal point of the mirror.

By the modification of the optics in the transmitter, this unit was improved to utilize all of the light from the discharge column. A fairly simple adjustment of the lamp along the axis also was able to be made, an arrangement which made it possible to adjust the width of the emergent beam to some extent. However, due to the fact that the source is extended (4 cm), it was impossible to get a radiation pattern where the light was not subjected to collimating effects. This always gave relatively more radiant energy near the optical axis, which, in the case of a submerged transmitter, would still tend to add to the vertical range proportionately more than to the horizontal range.

In Fig. 2, the solid curve is drawn through a polar plot of points in a plane representing luminous intensities in a field three-fourths of a mile from the transmitter, and the dotted curve shows the type of light distribution which would be more desirable. The measured beamwidth at the half-intensity point is 44 degrees. Since the flashtube was placed on the otpical axis, no difference in pattern could be expected for plots in other planes taken through the axis. If off-axis rays are measured in terms of angle vs absolute energies, it would be found that the divergent rays in Fig. 1 would contain appreciable energy out to about 40 degrees.

Another advantage that comes from placing the flashtube on the optical axis is the marked reduction in spatial jitter due to erratic displacement of the discharge path from one flash to another. The variation in intensity at any off-axis point was found to be less than 20 percent for a large number of flashes.

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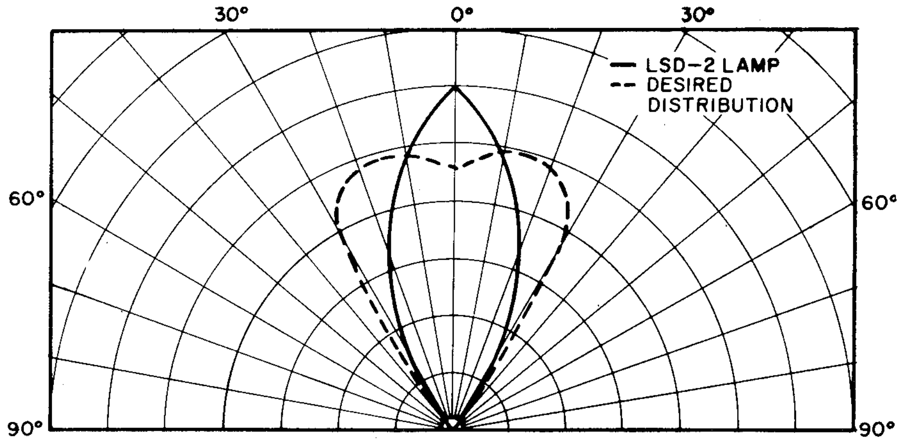

Fig. 2 - Relative light intensity from LSD2 lamp in parabolic reflector. The dashed curve indicates a more desirable distribution needed to improve horizontal range.

In a forthcoming NRL report full details of the redesigned transmitter which was used in this study will be presented. These details will include a parallel thyratron circuit for firing the flashtubes. Such an arrangement eliminates special trigger transformers and trigger probes in the lamps. Pulses on the hydrogen thyratron grids give control over the firing through the discharge circuits. This control may be manual or automatic to produce a flash rate up to five flashes per second (fps).

For the field trip described later in this report, two energy storage capacitors were used, each with a rating of 0.05 μf and 16 kv. These were operated in parallel so that the capacitance value was a nominal 0.1 μf, and the lamp was operated at 10 kv break-over voltage. Using the relation

$$W = 1/2\ CV^2 \text{ watt-sec,}$$

(where C is capacitance in farads and V is voltage in volts) it was determined that the discharge energy was approximately 5 watt-sec per flash.

Careful time measurements of the light flash with a phototube and oscilloscope gave 0.4 microsecond for the length of the light pulse at the half-intensity points. With the setting of the flash rate at 2 fps for the field trip, the average energy dissipated in the discharge circuit and used by the lamp was only 10 watts. However, the peak power fed into the lamp reached probable values of around 10 megawatts.

RECEIVER SENSITIVITY PATTERN

The receiver equipment was essentially the same as that used in previous field experiments except that the photomultiplier pickup unit was changed. This was done to increase the sensitivity in the horizontal direction.

In Fig. 3 may be seen two 5819 photomultiplier tubes with axes at an angle of 90 degrees. This combination was mounted downward in the aircraft so that one tube pointed in the forward direction and the other pointed backward. By doing this, a wide pickup field was made

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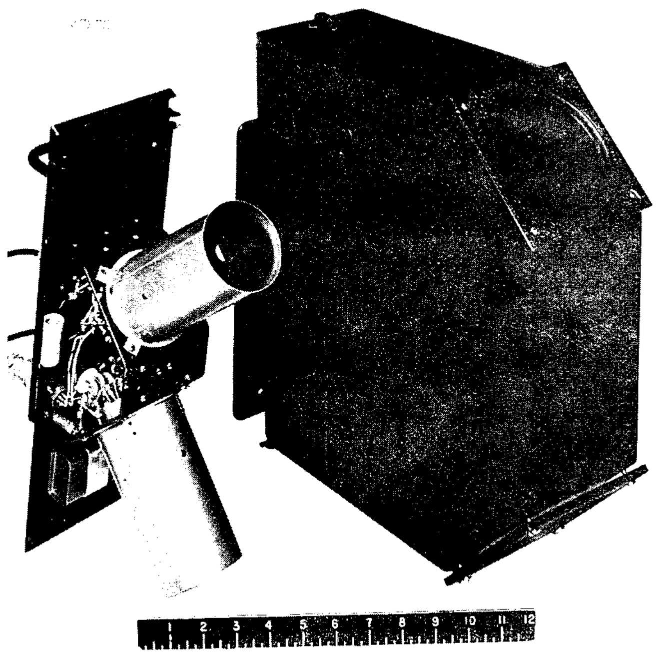

Fig. 3 - Detector unit of the receiver. Both the electronic section and the housing are shown.

available with sensitivity advantages for an experiment where the aircraft flies along the course of a submerged submarine.

Both of the multiplier tubes and the other electronic components are shock-mounted by conventional means inside a housing which is also shown. Due to housing difficulties and some projections on the bottom of a P2V airplane no wider angle was attempted with the photomultipliers.

Two ports are provided for the multiplier tubes. Circular disc filters could be attached and held in place by frames which were placed on the outside of the housing. Clear Lucite discs or lenses can also be used although the installation must be made while the aircraft is on the ground. For the results described in this report, it may be pointed out here that only clear Plexiglas discs were used.

A sensitivity plot of the receiver is shown in Fig. 4. All points were taken in a plane through the main axes of the two multiplier tubes. This would coincide with a vertical plane through the nose and rudder of an aircraft when the pickup unit is installed on the bottom of the fuselage.

Such a simplified and fixed detector unit is characterized by a wide angle pickup field with no optical gain and a reduced signal-to-noise ratio. This ratio may be considerably lowered when solar reflections and other conditions are encountered, but for general data collecting it is perhaps better to use a wide-angled system with no special optical systems attached.

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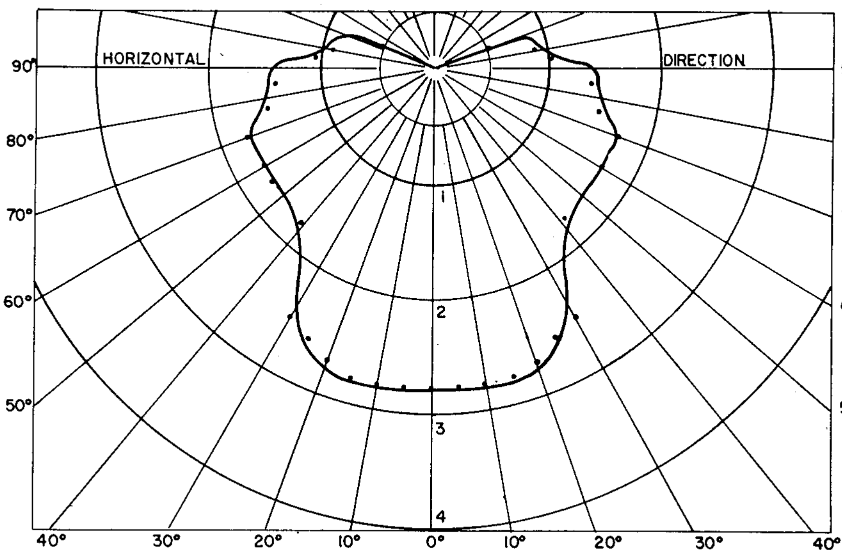

Fig. 4 - The relative sensitivity of the receiving unit. Two multiplier tubes are mounted 90 degrees apart and placed in a downward direction.

OPERATIONAL DETAILS OF A DAY-NIGHT RUN

Preliminary arrangements were set up in September 1957 between the submarine USS TUSK, stationed at Electric Boat Company, Groton, Connecticut, and a P2V-5 from the Air Station at Brunswick, Maine. The operating points were chosen in the Block Island area off the coast of Rhode Island since the submarine had other operations in this area. All the experiments were actually performed slightly east of Block Island. The runs began at a point approximately 4[redacted]°10′N, 71°10′W during the daylight-to-night period on September 18.

A prearranged schedule patterned after the ones outlined in a previous report† was used to effect a rendezvous and make the runs. The P2V-5 flew out of Brunswick Air Station, and after several daylight flights over the submarine, the first runs were begun at 1800.

By setting on a fixed course and diving to an initial keel depth of 40 feet, the submarine held a speed of three knots for one-half hour. During this time the aircraft flew up and down the known course of the submerged craft which had the light-pulse transmitter operating on the forward deck. Three runs were made on the first course setting before the submarine surfaced for further instructions. Three subsequent series of runs were then made at keel depths down to 90 feet. As darkness came on, the gain of the airborne receiver could be set up and the best results were obtained without noise interference from the sun.

†NRL Report 4936, previously cited

[redacted]

RESULTS OF FIELD TRIP

With only slight loss of sensitivity due to some vibration in the 5819 photomultiplier tubes, all the equipment worked continuously and well. Seventeen separate runs were made and complete data were collected for fifteen of these runs. By measuring the time of clear signal reception and knowing the speed of the aircraft, it was easy to compute the range for all the cases. In Table 1 are presented the data on the whole test, including the negative results obtained in the daylight runs.

TABLE 1

Horizontal Ranges of Detectable Light Pulses from Submerged Transmitter*

Run Number	Submarine Keel Depth** (ft)	Aircraft Altitude (ft)	Air Speed (knots)	Detection Time (sec)	Horizontal Air Range (statute miles)	Time of Day
1†	40	500	160	0	0	1800
2	40	500	160	0	0	1810
3	Periscope	500	160	0	0	1820
4	40	200	Aircraft apparently off course			—
5	70	1000	150	23.0	1.09	1933
6‡	70	1000	150	26.7	1.28	1953
7	70	1000	150	15.6	0.76	2012
8	70	500	150	Range limited so that aircraft missed target		2033
9	70	500	155	8.0	0.40	2050
10	70 to 40	500	150	31.0	1.5	2107
11	40	500	150	67.2	3.3	2128
12	40	1000	150	82.0	3.9	2143
13	40	1000	150	59.0	2.8	2202
14§	40 to 90	1000	150	68.0	3.3	2225
15	90	1000	150	26.0	1.25	2245
16	90	1000	150	39.0	1.9	2301
17	90	1500	150	21.0	1.0	2323

*The weather was cloudless and hence visibility was good; the sea was scattered with white caps and the water was fairly green and murky.

**Keel depth = transmitter depth plus 27 feet

†Full daylight—reflected sun

‡Flashing transmitter seen by observer—twilight

§Data taken while the submarine was diving

According to the observer in the aircraft, the rays from the sun were reflected directly into the receiver photomultiplier tubes so that successful daylight results could not be recorded. The two factors which prevented successful daylight operations were the low transmission of the murky coastal water and the omission of ultraviolet filters over the receiver. This latter condition was imposed on the operation partly by the optical transmission of the thick (1-inch) Pyrex window on the submerged transmitter. Although the LSD2 flashtube has high radiant energy in the near-ultraviolet region (320-400 mμ), the transmission of the glass (Fig. 5) made it desirable to use light in the visible region. The effective wavelength band in all runs was approximately 400 to 580 mμ which may be considered best for coastal waters.‡ As a matter of experimental fact it may be stated at this point that the operation of any pulsed-light system in murky coastal water is limited to such an optical band. This means that for positive operation of the equipment, only nighttime conditions can be considered.

A study of Table 1 will show some variation in the measurement of ranges at fixed transmitter depths. This is perhaps due to the difficulty in flying through the vertical line over the point from which the light emanates. The correct horizontal ranges probably are near the highest values given in the range column.

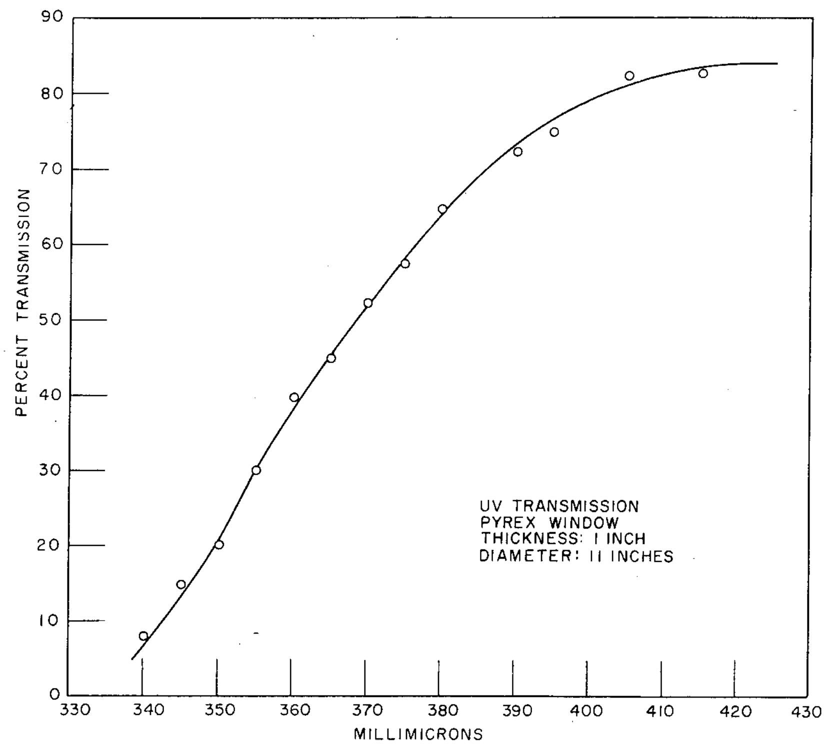

Fig. 5 - Transmission curve of inch-thick Pyrex window used in the underwater transmitter housing

‡D. F. Hansen, W. S. Plymale, Jr., and G. L. Stamm, "Investigation of a Pulsed-Light IFF System for Use Between an Aircraft and a Submarine," NRL Report 4382 (Secret), July 1954

[redacted]

SUMMARY

As a result of the tests performed to date, there are summarized below the performance limits that may be expected owing to various conditions of operations. Future studies may point out changes. From the results shown in Table 1 and other data outlined in previous NRL reports, the horizontal air ranges can be estimated as controlled by the following conditions of operation:

1. Estimated air ranges during daytime operations in clearest coastal waters are 1 mile when:
   a. wavelengths are limited to below 580 mμ,
   b. weather is cloudy with no direct sunlight,
   c. transmitter depths are less than fifty feet.

2. During nighttime operations in coastal waters, horizontal air ranges can extend up to several miles at a height of 500 feet or above when:
   a. wavelengths are limited to visible region,
   b. weather varies from clear to hazy,
   c. transmitter depths are less than 100 feet.

3. Estimated air ranges during daytime operations in clearest sea water are $\leq$ 1 mile when:
   a. wavelengths are limited to below 370 mμ,
   b. weather varies from overcast skies to bright sunlight,
   c. transmitter depths are less than 200 feet.

4. For nighttime operations in average clear sea water, the air ranges are 4 to 5 miles for aircraft altitudes of 500 to 10,000 feet when:
   a. wavelengths are either in the visible or ultraviolet bands,
   b. weather varies from clear to hazy,
   c. transmitter depths are up to several hundred feet.

In general it may be said that sea state does not affect the ranges to the degree that ambient illuminations and atmospheric conditions do. For a fixed energy pattern in the transmitter beam a higher sea state will decrease vertical ranges and slightly increase the horizontal ranges.

Summarized below are the favorable and unfavorable weather conditions for the air ranges during day and night operation.

	Day	Night
Favorable:	clouds, haze, very low sun	clear, good visibility, high cloud layers
Unfavorable:	bright sunlight, direct reflections	fog, low haze, full moon

[redacted]

The conditions that are favorable to good nighttime operation are also favorable to operations at dawn and at dusk. Sunlight, especially on a cloudless day is the largest detrimental factor although limited results have been obtained on clear days with very intense sunlight.

PLANNING OF FUTURE FIELD TESTS

The data obtained thus far in field experiments show that the pulsed-light system is feasible for horizontal ranges up to several miles and submarine depths down to several hundred feet. However, these values may go down to nearly zero when daylight transmissions are attempted in murky coastal water.

Since collection of further data requires the services of a submarine and some type of aircraft capable of long ranges, the test procedure becomes more involved. All the difficulties of constructing equipment for underwater pressures and aircraft installations make it necessary to give more attention to design. This is especially true of the submarine installation where operating depths and safety factors require that the casings and windows be made to withstand hydrostatic pressures for depths of 500 to 1000 feet.

The main problem on the submarine equipment is the construction of the window. For broad radiation fields it is necessary to have a circular aperture of nearly nine inches in diameter and such a window will require special design. The proper solution to this problem will include the pouring of a high silica glass or fused quartz lensatic window and the molding of a heavy metal cap for the transmitter housing.

If a two-way system is adopted, the problem of designing a suitable airborne transmitter will necessitate the construction of 400-cycle transformers and other special components. Also, the installation will be more complicated than for the receiver alone, since the lamp and reflector flash unit will be on the outside of the plane.

As the design problems are rather extensive, it is suggested that a complete review be made by all interested groups of the Navy to determine what further uses should be made of the pulsed-light system and how far plans should be carried to construct and install equipment suitable for operational service in fleet units.

EXPERIMENTAL PLANS FOR IMPROVING FLASHLAMPS

The lamps now being used are the Mullard Type LSD2 which are made in England. These lamps are filled to a pressure of one atmosphere with argon and have a gap width of four centimeters. They were made for high-speed photographic uses and were not designed for such service as is needed in a pulsed-light system. Soft copper electrodes and other features shorten the life of such lamps, although some have given continuous rapid-flash service up to fourteen hours.

Work is being done at the present time on some experimental lamps having a gap width of two centimeters. They are being designed with the following features:

a. rugged construction,

b. special electrodes for broader arcs,

c. tritium used as an ionizing agent,

d. high pressure fillings,

e. flashover voltage range especially chosen for thyratron control, and

f. better optical control due to shortening of arc.

These improvements are needed to get a serviceable lamp to operate in the thyratron-fired transmitter that is now being used with flash rates up to five flashes per second.

There are plans to continue the work on these experimental flashlamps. Much of the work, especially the spectral energy measurements, is tedious and time consuming. Nevertheless, it is believed that lamps of this type will have future use in such fields as ground-to-air and air-to-air systems which depend on pulsed-light sources of very high peak energies in the near ultraviolet or visible region of the spectrum.

* * *